A pilot study for using non-heating volunteer experiments as a surrogate for in-patient MR thermometry reproducibility during MR-hyperthermia

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Background

During hyperthermia treatments, tissue temperature is locally elevated to 40-44 ℃ with the objective to sensitize tumour cells for chemo- and/or radiotherapy with the ultimate goal to enhance clinical outcome[1]. The MR-hyperthermia hybrid system is an ideal technological platform to non-invasively monitor temperature and guide dose-optimization in real-time. The Proton resonant frequency shift (PRFS) method is the most frequently used method for MR thermometry (MRT) [2]. The PRFS method measures temperature changes using differential phase maps. Unfortunately, it is sensitive to patient motion, which affects the MRT accuracy. Motion also affects PRFS when no heating is applied, so many studies utilize non heating experiments in volunteers to assess MRT reproducibility, i.e. temporal precision, but it is unclear if this approach is suitable.

Aim

This pilot study aims to validate if in vivo MRT reproducibility can be studied in volunteers without the need for patient studies. The follow-up of this study in volunteers will enhance progress in solving the inaccuracies that this technique poses. Besides, we also studied if using covariance filtering is a suitable way to exclude low MRT data with low SNR.

Conclusions

This study showed a mean temperature reproducibility of 0.2°C for both volunteers and patients, which indicates a high degree of closeness to the true temperature change (0°C). Our results also indicate that the standard deviation of temperature changes after masking is substantial, but that regions can be discriminated where the errors are clinically acceptable. In conclusion, we found good agreement between MR-thermometry reproducibility in patients before and during heating and that found in non-heating studies in volunteers. This pilot study constitutes the validity of using volunteers to estimate motion induced artefacts in MR thermometry and to improve its accuracy.

Methods

A clinically-standard dual-echo gradient-echo sequence protocol was implemented, in which always two PRFS scans were performed directly after each other, as presented in **Figure 1A**. Three anonymized patient data were included and the baseline (non-heating) procedure was performed twice in a similar fashion for three volunteers. Patients and volunteers were placed inside the BSD-2000-3D-MR that was placed into a 450w 1.5T MR scanner. The subtraction of two PRFS scans led to 2D temperature difference maps (dT_map), as presented in **Figure 1B**. dT_maps were evaluated for baseline (“volunteer baseline”, “patient baseline”) and during treatment (“patient treatment”). Covariance thresholding was applied to mask the areas with a low signal-to-noise . Precision was assessed by the standard deviation of the temperature maps. Reproducibility was evaluated by the mean absolute change measured directly from dT_maps [3].

MR protocol and dT_map calculation

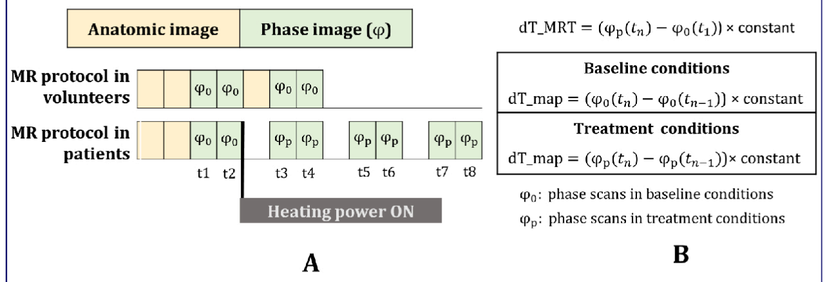

***Figure 1**: (A) MR protocol for patients and volunteers; (B) Temperature difference map (dT_map) calculation in baseline and treatment conditions. dT_MRT represents the calculation of MR thermometry for monitoring temperature dynamics during the treatment. In both formulations, constant represents the PRFS constant.*

Results

Figure 3 presents the dT_map from a volunteer (**Figure 3A**), the applied covariance mask combined with the body contour mask (**Figure 3B**) and the final dT_maps (**Figure 3C**) that form the input for the quantitative evaluation. **Figure 4** shows boxplot and histogram representations of all pixels of the masked dT_maps for the three scenarios. The median of all the distributions is approximately zero, confirming our assumption that all measurements were taken in steady state. **Table 1** presents the mean temperature difference (μ) and standard deviation of the differences (σ) for all subjects and measurements combined (before / after covariance mask). The temperature reproducibility in both groups was 0.2 ° C . The maximum temperature precision for baseline conditions and treatment conditions was 2.7° C and 3.4° C, respectively.

Temperature error maps

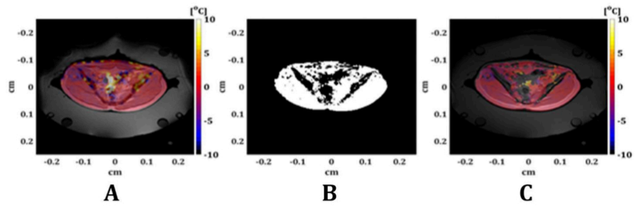

***Figure 3**: (A) un-masked dT_map on top of the intensity image of the PRF scan; (B) covariance mask; (C) masked dT_map on top of the PRF scan intensity distribution.*

Boxplot and histogram representations of all pixels

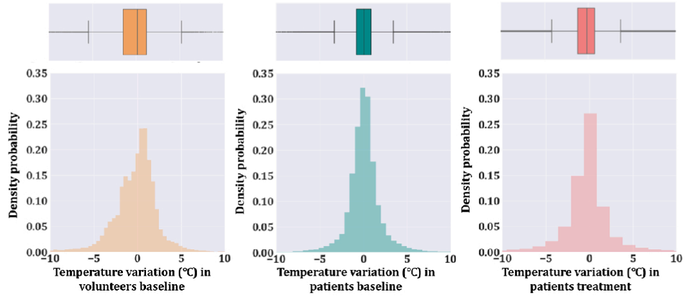

***Figure 4:** Boxplot and histogram of all the pixels of the masked dT_map after for the three scenarios. The x-axis represents the temperature variation (°C) and the y-axis is the density probability*

Statistical parameters

	σ		μ	
	BC	AC	BC	AC
Volunteers baseline	4.4°C	2.7°	0.3°C	-0.2°C
Patients baseline	4.5°C	2.4°C	0.4°C	0.2°C;
Patients treatment	4.3°C	3.4°C	-0.1°C	-0.2°C

***Table 1:** The standard deviation of the differences (σ) and mean temperature difference (μ) for all subjects and measurements combined (before covariance mask (BC) ; after covariance mask (AC))*

References

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